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ABSTRACT. Machine processing techniques were applied to multispectral data obtained from airborne scanners at an elevation of 600 meters over central Indianapolis in August, 1972. Computer analysis of these spectral data indicate that roads (two types), roof tops (three types), dense grass (two types), sparse grass (two types), trees, bare soil, and water (two types) can be accurately identified. Using computers, it is possible to determine land uses from analysis of type, size, shape, and spatial associations of earth surface images identified from multispectral data. Land use data developed through machine processing techniques can be programmed to monitor land use changes, simulate land use conditions, and provide "impact" statistics that are required to analyze stresses placed on spatial systems.

A portion of the budget of every city and county is allocated to the collection of land use data. A planning agency must have information pertinent to a variety of users. Often these information systems are costly, require many people, and are slow. This paper explores the alternative of using computer-implemented analysis of airborne spectral scanner data to monitor urban land use.

DATA ACQUISITION AND DATA PROCESSING

An area of varied land use in central Indianapolis was selected for this study (Fig. 1). This test area includes residential, recreational, industrial, commercial, transportation, and institutional land uses. Multispectral scanner data were recorded at an altitude of 600 meters (2,000 ft.) on 10 August 1972 at 16:12 hours. Electromagnetic responses from earth surface features in the study area were recorded in twelve spectral bands (Table 1). Eight bands were in the visible part of the spectrum, three in the reflective infrared, and one in the thermal infrared.

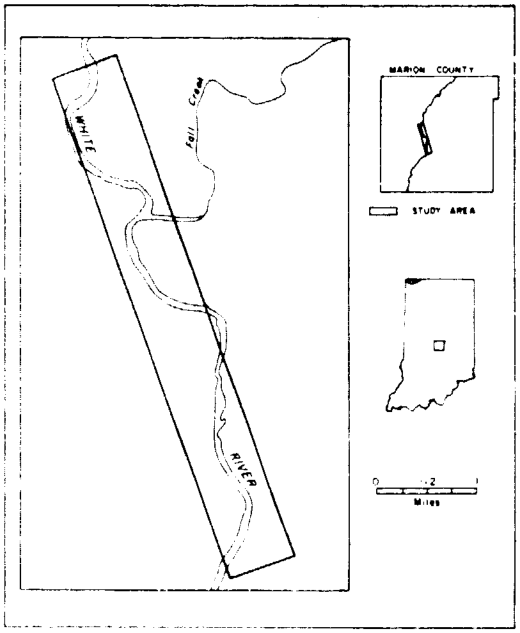

Fig. 1. Central Indianapolis study area.

A wide range of the electromagnetic spectrum is reflected and emitted continuously from the earth's surface. An airborne or earth-orbiting multispectral scanner is designed to measure the energy within several specific wavelength bands. Thus for every area being monitored or scanned by multispectral sensors, a broad array of spectral data may be obtained. Since spectral data are recorded on magnetic tape and then digitized and arranged in lines and columns, they may be readily processed by a digital computer. The programs used in this study analyze several spectral bands and identify earth surface features by the differences in spectral responses. A surface feature that is spectrally separable (that is, having a unique spectral response in one or more, but not neces-

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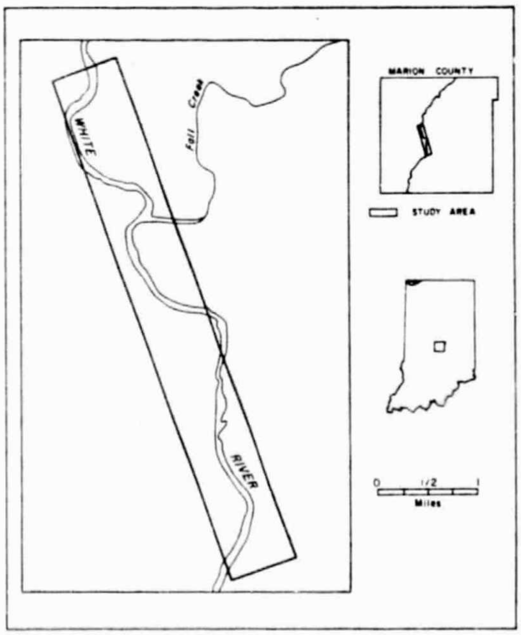

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TABLE 1. SPECTRAL BANDS USED IN COMPUTER-IMPLEMENTED PROCESSING OF AIRBORNE MULTISPECTRAL SENSOR DATA

Band Number	Wavelength (micrometers)	Portion of Electromagnetic Spectrum
1	.41– .48	
2	.46– .49	
3	.48– .52	
4	.50– .54	Visible
5	.52– .57	
6	.55– .60	
7	.58– .64	
8	.62– .70	
9	.67– .94	Reflective Infrared
10	1.00– 1.40	
11	2.00– 2.60	
12	9.30–11.70	Thermal (emissive) Infrared

Source: Authors.

sarily all wavelengths) from all other features in a given study area is a good candidate to be identified accurately in a pattern-recognition classification program.

Images of band six (.55 to .60 micrometers), ten (1.00 to 1.40 micrometers), and twelve (9.30 to 11.70 micrometers) were photographed from a digital display, an instrument which provides a television-like image of the digitized data (Fu, Landgrebe, and Phillips, 1969). Data were also displayed on alphanumeric line printer maps. Representative areas of various ground cover types thought to have spectrally separable characteristics were chosen for analysis. The training samples, as such representative areas are termed, were located either on the digital display or the alphanumeric line printer maps by association of the imagery with aerial photographs (Indianapolis Power and Light Company, 1972). The location (line and column coordinates) of a number of small rectangular training samples for each class of ground cover was recorded. Statistics (means, standard deviations, and covariance matrices) from training samples in each class were then calculated to give a quantitative, spectral characterization of each ground cover type.

All of the data points in the line of flight could have been classified on the basis of the twelve band statistics, but such a job would have required excessive computer time. Consequently, a separability program was used to select the best four bands to use for classification. Bands one (.41 to .48 micrometers), six (.55 to .60 micrometers), ten (1.00 to 1.40 micrometers), and twelve (9.30 to 11.70 micrometers) were chosen. On the basis of the statistics from these four bands, every point in the line of flight was classified into one of fourteen classes using a Gaussian maximum likelihood classification (Wacker and Landgrebe, 1971). The classes "roof top" (three types), "road" (two types), "dense grass" (two types), "sparse grass" (two types), "trees," "bare soil," "water" (two types), and "shadow" were identified.

CLASSIFICATION RESULTS

Three separate variations of the classification were displayed to highlight general classes of earth surface, cultural, and natural features, respectively. Three types of roof tops were identified. The class "roof top three" appeared dark in the visible and reflective infrared whereas "roof top one" and "roof top two" were bright in all bands. The great majority of the residential structures were classified as "roof top one" or "roof top two" whereas data points in the larger structures (industrial, commercial, or institutional) were classified in any one of the three roof top classes. The roof top structures in the study area were identified correctly approximately ninety percent of the time as validated by comparing known land use data to samples of the study area classified from airborne multispectral sensor data.

The two types of roads identified strongly suggests a strong spectral separability between concrete and asphalt materials. The "road one" category, concrete roads, was the more reflective of the two classes. Class "road two" or asphalt roads occurred much more frequently. This type of road (similar to "roof top one" and "roof top two")

was confused to a minor degree with areas of gravel or bare soil; however, the accuracy attained in the identification of roads was comparable to that of roof tops.

Five classes of vegetation were identified; four were characterized by open grassy areas and one by trees. "Trees" were identified with a high degree of accuracy (over ninety percent correct). The four spectrally distinct grassy areas were separated into the two general categories designated as "sparse grass" and "dense grass" respectively. The former comprised a major earth surface feature in the study area and was found in cemeteries, along parkways, and in open areas near railroad tracks. "Sparse grass two" had more bare soil showing than "sparse grass one." Principal areas classified as "dense grass" included: selected parks, spots on the grounds of the Indiana University Medical Center, the outfield of Bush Stadium, and a golf course. "Dense grass one" was somewhat more reflective than "dense grass two."

The general class "water" was identified with very high accuracy (approaching 100 percent). Two spectral classes were identified. All water was classified as "water one," with two major exceptions: a northern section of the White River and water associated with a golf course. It is likely that this "water two" category (the most reflective water class) contained a higher silt load. The other spectral classes identified were "bare soil" and "shadow." The former was found primarily in the southern portion of the study area and the latter was largely limited to two small areas adjacent to two tall buildings.

LAND USE CLASSIFICATION BY COMPUTER IMPLEMENTED ANALYSIS OF MULTISPECTRAL DATA

An accurate classification of earth surface features has been produced by computer-implemented analysis of multispectral data. An urban land use specialist could, by hand, superimpose lines defining land uses onto such a classification. However, such an effort might be questionable since photographic data collected at higher altitudes could yield comparable results. We are inclined toward the development of procedures for the rapid, computer-implemented classification of land uses with little human intervention. Of significance in this Indianapolis case study is the fact that a punched deck of approximately 100 computer cards alone provided the data by which computer analysis could identify urban surface features.

If multispectral remote sensing and computer-implemented analysis techniques are to be used most effectively in urban land use management, the analyst should have the capability to: (1) overlay all spectral data into a single mosaic of the area of interest (whether it be for display purposes or for purposes of calculation), (2) overlay sets of data collected at different times in a form that can be used either for display or calculation purposes, and (3) project all spectral data points onto a digital image at a scale useful to the analyst. An important capability would be the automatic identification of specific land uses. The computer could be programmed to search out and identify known areal patterns of earth surface feature combinations (i.e., grass with patches of trees characteristic of a type of recreation land use) that characterize types of land use (Fig. 2).Changes in land use could be identified readily.

Assuming that ground surface features are spectrally separable, computer programs could be written to automatically identify the described land uses. This identification is possible through analyzing the type, size, and shape of earth surface features and, of most importance, the spatial associations and relationships between those earth surface features. Thus the urban land use identification program should accomplish the following tasks: (1) classify an areal agglomeration of points, (2) identify the various earth surface features within that areal agglomeration, and (3) identify, through spatial association of earth surface features, various land uses within the agglomeration. It is important to note that automatic identification of both earth surface features and land uses is essential.

The sequence of land use identification is illustrated for a small area with diverse land uses (Fig. 2). Shown is a simulation of a point by point classification made of the area (Fig. 2A) and an example of how size and shape characteristics, in conjunction with spectral characteristics, was used to identify specific earth surface features (Fig. 2B). Industrial roof tops and residential roof tops were of the same spectral class, but size determined the separation. The pond and stream were both classified as "water," but shape was the clue to their correct identification. In a third step the computer associated the spatial arrangement of the earth surface features to identify broad land use categories (Fig. 2C). The residential area was characterized by an agglomeration of relatively closely spaced residences separated by trees and grass. The recreational land use (identified as a

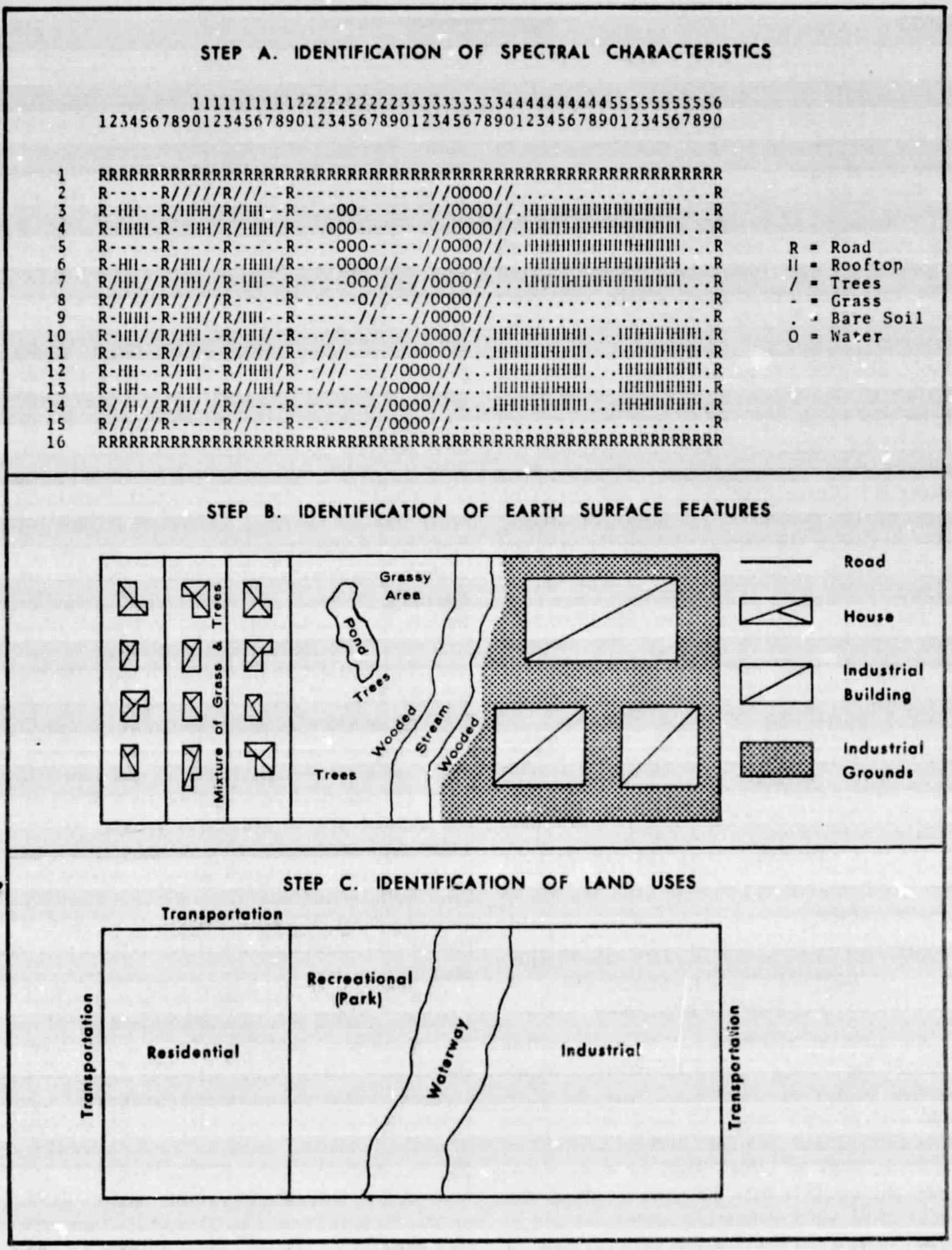

Fig. 2. Steps in computer identification of land use from spectral and spatial analysis of multispectral scanner data.

park) was typified by broad expanses of grass with scattered strands of trees and a small pond. The waterway was closely associated with the trees along the banks of the stream. Finally, the industrial area consisted of large buildings surrounded by bare soil.

Quantitative information for the area can be printed out by the computer (Fig. 2). Each data point (image resolution element) was 5.25 meters long and 4.20 meters wide, an area of .0022 hectares. Additional information may be inferred by the number of houses in the residential area. Assuming that all twelve residences were single-family dwelling units and that the mean population of such a unit was 3.2 persons, the estimated population of the residential area is thirty-eight.

There are numerous applications of the approach suggested. Impact studies can be used to ascertain stresses on school systems, parks, playgrounds, sanitary facilities, highways, traffic densities, evacuation routes, utilities, governmental units, service facilities, and mass transportation systems. Intelligent development of rural as well as non-rural lands in metropolitan environments can be enhanced through use of the suggested approach. The ability to immediately monitor changes in earth surface and land use features is a technological reality. Monitoring can add new dimensions to spatial analysis and the understanding of many contemporary spatial problems.

SUMMARY AND CONCLUSIONS

Important land cover types in urban areas are spectrally separable. Analysis of multispectral data collected over Indianapolis from an altitude of 600 meters indicated that "roads" (two types), "roof tops" (three types), "dense grass" (two types), "sparse grass" (two types), "trees", "bare soil", "water" (two types), and "shadow" are spectrally distinct classes. The ability to separate earth surface features in urban areas at this level of generalization is significant because it allows identification of very specific land uses. Given the capability to identify land uses, monitoring of land use change is possible by temporal overlay of airborne multispectral scanner data. The land use changes delineated by spectral analysis could be shown on a digital display or they could also be quantified by the computer-implemented analysis of the spectral statistics. Further processing of these data would result in "impact" statistics or calculations of the effects of a land use change on neighborhoods or entire communities.

Initial cost of an effective land use monitoring system would be high. Cost sharing of the system with federal, state, county, and city governments could make a monitoring system feasible. Most large metropolitan areas have a serious need for timely and accurate land use monitoring to facilitate effective urban and regional planning. Computerized information systems for the handling of temporal land use data are essential to meet spaital data demands of the future.

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